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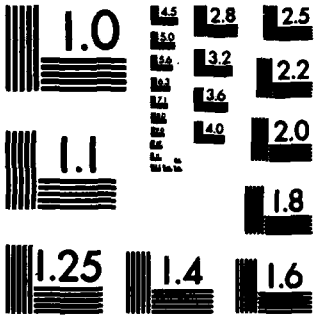

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Nonlinear properties of solids and liquids are studied. Both pulsed and cw ultrasonic waves are used in the ultrasonic measurements which are made by electronic as well as optical techniques. Nonlinear properties of solids such as single crystal $KZnF_3$, Ge, Si, NaCl, etc. are described in terms of third-order elastic constants which can be measured between room temperature and 4°K; those of liquids are described in terms of the ratio B/A of coefficients in the equation of state. Nonlinear diffraction theory is considered. Key words include:

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ANNUAL SUMMARY REPORT

of

Contract N00014-81-K-0229

Made to

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Physics Program (Code 412)
Arlington, VA 22217

Title: Nonlinear Acoustics

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I. ANNUAL SUMMARY REPORT

A. Nonlinear Properties of the Fluoroperovskites (Cubic Symmetry)

In addition to measurement of the nonlinear properties of the fluoroperovskites $CsCdF_3$ and $KZnF_3$ at room temperature published last year [M. A. Breazeale, J. Philip, A. Zarembowitch, M. Fischer, and Y. Gesland, J. Sound and Vib. 88, 133-140 (1983)], we have taken data on the temperature dependence of the nonlinearity parameters down to 77°K and have analyzed the results. With data on the pressure dependence of velocity in the same samples we will be able to isolate all six of the third-order elastic constants of these two perovskites between room temperature and 77°K. Such information can contribute greatly to an understanding of the physical properties of these solids. The samples were borrowed from A. Zarembowitch in Paris, who currently is taking the pressure-velocity data. A manuscript covering our results is essentially completed, and is to be submitted for publication shortly. If his data should arrive before submission, then a second joint paper will be submitted instead.

B. Nonlinear Distortion of Ultrasonic Waves in Crystals of Hexagonal and Trigonal Symmetry

In the course of writing the final draft of Technical Report No. 22 on the theory of nonlinear distortion of ultrasonic waves in crystals of hexagonal and trigonal symmetry, a mathematical error was discovered which necessitated re-examination of the entire theory. The re-examination has been completed for hexagonal symmetry, and this phase of the work will be reported in Technical Report No. 22. The theory of finite amplitude waves in trigonal crystals currently is being subjected to the same scrutiny and

will be given in a correct form in a later technical report. The error arose because of the tremendous number of terms generated when one uses a rotation matrix to derive the nonlinear wave equation for propagation along directions other than the principal axes. The experience gained makes possible a significant investigation for the current renewal period, so the discovery of an error proved to be a blessing in disguise.

C. Relationship between Surface Acoustic Waves on, and Bulk Waves in, Nonlinear Cubic Crystals

Much of the investigation of the relationship between bulk waves and surface waves in the nonlinear regime is funded by another agency; however, one aspect of that investigation has bearing on our future investigations and hence is worthy of mention. In formulating the theory in a sufficiently general form to include description of the effect of nonlinearity in a cubic crystal on surface wave propagation (a surface wave is not a pure mode, but even in the simplest case the theory must include terms resulting from coupling of the longitudinal mode to a transverse mode), we have gained insight into the problem of handling nonpure mode propagation in a nonlinear medium. This insight is suggesting new approaches to the nonlinear acoustics of solids.

D. Diffraction Theory in the Nonlinear Approximation

The general problem of a nonlinear diffraction theory (or the lack thereof) enters directly into our evaluation of TOE constants, and affects the accuracy of our data. For this reason we have taken data on the nonlinear distortion of finite amplitude waves in known samples with transmitting and receiving transducers having diameters between 2 mm and 12 mm. The results, which have enabled us to define a diffraction correction for

our data, are described in a publication in the Journal of the Acoustical Society of America. In the meantime, a nonlinear diffraction theory by Tjøtta and Tjøtta and co-workers has appeared in the same journal. The implications of the Tjøtta theory for our situation has been of great interest to us.

E. Apparatus Modification

1. The transistor IF amplifier designed to amplify the 60 MHz component of an initially sinusoidal 30 MHz ultrasonic wave has been purchased. After careful measurement of the characteristics of the amplifier, it was mounted in the apparatus, and at present is awaiting a person skillful enough to use the system to take meaningful data.

2. The schlieren system for optical investigations of ultrasonic wave propagation in transparent fluids has in it an excellent goniometer which was described in Technical Report No. 18. However, the system has always given problems in the study of reflection of ultrasound from complicated structures such as solid gratings. A second goniometer for holding the reflector was needed. Such a goniometer which is capable of translation and rotation about two axes (and can be submerged) has been designed and at present is under construction.

F. New Directions in Research

In addition to Investigations A, B, C, D, and E above, our effort has been directed toward three relatively new goals:

1. Determination of the most accurate procedure for evaluating second-order elastic constant combinations required for evaluation of TOE constants

In evaluating TOE constants from harmonic generation experiments one finds that the accuracy always is affected by the accuracy of knowledge of

those specific combinations of second-order elastic constants found in the expression for the longitudinal wave velocity in the appropriate crystallographic direction. Heretofore, readily available data on second-order elastic constants has been used without sufficient consideration of error propagation. In fact, it now appears that greatest accuracy will be obtained by evaluating longitudinal wave velocities anew as the TOE constant data are taken. A comparative study of the error propagation in the two cases is in progress. Velocity measurements in previously measured samples are providing new data and the information necessary to evaluate error propagation in the two cases. Future procedures in the measurement of TOE constants will depend on the outcome of this investigation.

2. Development of a transducer for producing a Gaussian profile in two dimensions

The transducer for producing a Gaussian profile across one dimension has been very successfully used for schlieren photography in which a long thin strip electrode was aligned with the direction of the light wave propagation [J. Acoust. Soc. Am. 70, 1791 (1981)]. The alignment eliminated sidelobes from the ultrasonic beams in our schlieren photographs. Now it appears that a two-dimensional Gaussian profile would provide a unique opportunity for comparing theory and experiment in nonlinear acoustics. For this reason, and others, a considerable amount of effort has gone into design of a Gaussian transducer and analysis of its output. So far we have designed a transducer and have confirmed the Gaussian distribution. In addition, we have been able to confirm the fact that no longer do we have a Fresnel field in the beam pattern. The Gaussian behavior exists at very small distances. The elimination of the maxima and minima characteristic of the Fresnel zone has far-reaching technological implication. A paper has

been submitted for presentation at the Minneapolis meeting of the Acoustical Society of America.

3. Understanding coupled-wave propagation in nonlinear anisotropic media

The coupled-wave problem found in the description of nonlinear distortion of surface acoustic waves on nonlinear anisotropic media has been solved for cubic symmetry, and was discussed at the 10th International Symposium on Nonlinear Acoustics in Kobe, Japan. This success has led to a re-examination of the description of the transverse wave propagation along principal directions in cubic crystals with the hope that one can measure another combination of third-order elastic constants by a suitably ingenious technique. Although the technique has not been realized yet, at least we have been able to make a perturbation solution to the nonlinear equation describing the transverse wave and show that it is coupled to the longitudinal wave.

G. Contributions to Scientific Literature

The following is a list of reports distributed during the year between December 1, 1983 to November 30, 1984.

1. Publications

a. "Nonlinear Distortion of Ultrasonic Waves in Small Crystalline Samples," Bruce D. Blackburn and M. A. Breazeale, J. Acoust. Soc. Am. Accepted for publication in October 1984.

b. "Measurement of Nonlinear Distortion of Bulk and Surface Acoustic Waves," M. A. Breazeale, G. Socino, and R. Bicocchi, Proceedings of the Tenth International Symposium on Nonlinear Acoustics (accepted for publication).

2. Papers at Scientific Meetings

a. "Ultrasonic Measurement of the Nonlinear Properties of Solids," M. A. Breazeale, 21st Meeting, Society of Engineering Science, October 1984 (invited).

b. "Measurement of Nonlinear Distortion of Bulk and Surface Acoustic Waves," M. A. Breazeale, Tenth International Symposium on Nonlinear Acoustics, Kobe, Japan, July 1984.

c. "A Comparison of the Nonlinear Acoustics of Solids with the Nonlinear Acoustics of Fluids," M. A. Breazeale, Nonlinear Acoustics Research Society of Japan, Doshisha University, Kyoto, Japan, July 1984 (invited).

d. "The Sound Field of a Gaussian Transducer," Gong-huan Du and M. A. Breazeale, 108th Meeting, Acoustical Society of America, Minneapolis, October 1984.

3. Technical Report

"Theory of Harmonic Generation of Finite Amplitude Ultrasonic Waves in Solids of Hexagonal Symmetry," Jacob Philip and M. A. Breazeale, Technical Report No. 22, October 1984.

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